U. S. NAVAL SCHOOL OF AVIATION MEDICINE
NAVAL AIR STATION
PENSACOLA, FLORIDA

JOINT PROJECT REPORT NO. 18

The Ohio State University Research Foundation
Columbus, Ohio, under Contract N6ONR 22525,
Office of Naval Research Project Designation No. NR 145-993

and

U. S. Naval School of Aviation Medicine
The Bureau of Medicine and Surgery Project NM 001 064.01.18

A MEASUREMENT OF THE TEMPORARY EFFECT OF NOISE UPON HEARING

Report prepared by

John W. Black, Chester J. Atkinson, Lieutenant Vernon Bragg, USNR, Scott N. Morrill, and Gilbert C. Tolhurst

Approved by

John W. Black
Project Director
and
Captain Ashton Graybiel, MC, USN
Director of Research
U. S. Naval School of Aviation Medicine

Released by

Captain James L. Holland, MC, USN
Commanding Officer

1 November 1953

U. S. Naval School of Aviation Medicine 1 November 1953

Joint Report NM 001 064.01, Report No. 18

A MEASUREMENT OF THE TEMPORARY EFFECT OF NOISE UPON HEARING

John W. Black, Chester J. Atkinson, Vernon Bragg, Scott N. Morrill, and Gilbert C. Tolhurst, Acoustic Laboratory, The Ohio State University, and U. S. Naval School of Aviation Medicine, Pensacola, Florida

13 pp. 11 tables 5 illustrations UNCLASSIFIED

A pulse-type test of hearing was devised for measuring the temporary hearing loss occasioned by the exposure of personnel to high-level noise. Pulses of white noise and 500-cycle tone were recorded on magnetic tape in 2-db decremental steps, and reproduced in a 64-sec. testing interval. (1) The tests were sensitive to the temporary hearing loss incurred through the exposure of ears to noise. (2) The two types of pulses apparently appraised different aspects of the hearing function. (3) The test had to be administered through equivalent forms five times for indoctrination. (4) The test correlated, r = .68 -.78, with word reception.

1. Otolaryngology. 2. Speech Correction and Hearing Problems. 3. Acoustics.

I. John W. Black II. Chester J. Atkinson III. Vernon Bragg IV. Scott N. Morrill V. Gilbert C. Tolhurst

PRESS RELEASE

In a joint program between the Naval School of Aviation Medicine and The Ohio State University a test has been devised for measuring the temporary loss in hearing that is occasioned by exposing personnel to high-level noise. The noise problem that was once the boiler maker's later overtook the aircraft pilot and now has become even more general. Relative measurements of the temporary loss of hearing can be obtained in 64 seconds in the Acoustic Laboratory of the School of Aviation Medicine at Pensacola, Florida. This project is assisted by the Office of Naval Research and is directed by Professor John W. Black of The Ohio State University.

Project No.: NM 001 064.01.18

Joint Project Report Title: A Measurement of the Tempora' y Effect of Noise Upon Hearing

Authors: John W. Black, Chester J. Atkinson, Vernon Bragg, Lieutenant, USNR, Scott N. Morrill, and Gilbert C. Tolhurst

REFERENCES

1. Andersen, T. B. An Evaluation of Two Pulse-Type Tests of Hearing. Unpublished doctoral dissertation. The Ohio State University (1952).

2. Black, J. W. The Effect of Noise-Induced Temporary Deafness upon Vocal Intensity. NM 001 064.01.07, Naval School of Aviation Medicine (1951).

3. Black, J.W. Multiple-choice intelligibility tests. NM 001 064.01.17, Naval School of Aviation Medicine. In press.

4. Davis, H., et al. Temporary deafness following exposure to loud tones and noise. Acta oto-laryng., Stockholm, Suppl. 88 (1950).

5. Hirsh, I. J. and Ward, W. D. Recovery of the auditory threshold after strong acoustic stimulation. J. acoust. Soc. Amer., 24, 131-141 (1952).

6. Kryter, K. D. The effects of noise on man. J. Speech and Hearing Disorders. Suppl. 1 (1950).

7. Lindquist, E. F. Goodness of fit of trend curves and significance of trend differences. Psychometrika 12, 65-78 (1947).

8. Rüedi, L. and Furrer, W. Physics and Physiology of Acoustic Trauma. J. acoust. Soc. Amer., 18, 409-412 (1946).

SUMMARY

Pulse-type hearing tests include as a single test item a cluster of "beeps" that listeners identify by counting. A "count" is right or wrong and may contribute to either a pass-fail score or a quantitative score. This principle of testing was employed in the construction of a test for assessing the temporary hearing loss of personnel exposed to controlled levels and spectra of noise for specified times. Pulses of "white" noise and 500-cycle tone were employed in a series of 2 db decremental steps. 1. The two types of pulses measure different aspects of the hearing function. 2. Five administrations of equivalent forms of the test are required for indoctrination. 3. A deviation up to 0.7 db in sound pressure level seems to be "expected" in the preparation and administration of the tape-recorded test and to be evident in diurnal variations of scores.

The test was adapted and coupled with a multiple-choice word-reception test and both were compared with more conventional pulse-type tests. The two conventional tests were found to be more similar to each other than to the present pulse test. The pulse test was more closely related to factors involved in word reception than were the comparison tests.

INTRODUCTION

The temporary damage to hearing that results from the exposure of listeners to high levels of noise has been measured and reported by Davis (4) and more recently by Rüedi and Furrer (8). A comprehensive summary of related work has been provided by Kryter (6). The investigations by Davis and Rüedi-Furrer employed sophisticated subjects and relied upon audiometers for measuring the threshold shift and the progress of the recovery of hearing. The levels of environmental noises ranged from 110 to 130 db, and the exposure times from 1 to 64 minutes. Davis' original report included related data concerning decrements in word reception scores (articulation tests) that resulted from exposure to noise.

One of us (2) reported that when experimental subjects, wearing conventional military headsets (HS-33), were exposed to 110 db of simulated propeller-type, airplane noise for two hours, the listeners talked "naturally" with 5 db greater sound pressure level; also that both this effect and the recovery from it were related to the listener-speaker's threshold shift at 500-cycles per second (c.p.s.)—the only test signal that was employed. This tone was presented to the subjects at three-minute intervals subsequent to the exposure to noise.

The manufacturers of naval aircraft are permitted the following tolerances in noise specifications for the cockpit: overall level, cruising 100 db, climbing 110 db, taking off 115 db; and in spectrum the level of the band 75-150 c.p.s. must not exceed 94% of the total, the band 600-1200 must not exceed 84% of the total, and the band 2400-4800 73% of the total. Flight personnel are expected to wear headsets or helmets that contain earphones. These attenuate the noise level at the ears of the operating personnel 10-15 db at 1000 c.p.s.

The ultimate objective of the present study was to appraise the temporary damage to the hearing of flight personnel that might result from single exposures of varying duration to noise of spectra and sound pressure levels relevant to the specifications immediately above. The immediate objective was to devise a test that could be administered in connection with a study of "the effects of noise" and that would 1. give an indication of the threshold shift of several hundred experimental subjects, not sophisticated in taking hearing tests, 2. permit a measurement of the momentary state of hearing with a minimum interruption of the exposure of the listeners to surrounding

noise, and 3. be applicable to groups of any number of experimental subjects. No clinical application of the test was envisaged.

Several testing procedures--modifications of standard group audiometric methods--were tried in preliminary trials. All were comprised of groups of pulses that were recorded on magnetic tape and reproduced binaurally over military headsets (HS-33) to listeners during brief interruptions in their exposure to high-level noise. The pulses in different trial forms of the test were: white noise, white noise through a 1600 c.p.s. low-pass filter, white noise through a 1600-2400 c.p.s. band-pass filter, white noise through a 2400 c.p.s. high-pass filter; the output of a sweep-frequency oscillator under the same three conditions of filtering; and tones of 125, 250, 500, 2000, 4000, 6000, and 8000 c.p.s. Initially the pulses were of six levels of sound pressure with incremental steps of two db. Each pulse was 0.1 sec. in duration; there were 2 - 4 pulses in a group; the period between successive pulses was 0.25 sec.; and the period between the final pulse in a series and the voice signal that introduced the next item was 1 sec.

Audiograms were secured from 30 normal-hearing male experimental subjects at the outset of a preliminary experimental session and again after exposure (wearing headsets) to approximately two hours of simulated aircraft noise, propeller type, 110 db. The audiometers were used. The subjects remained in the noise until called for their second audiometric tests. The first two subjects were tested after 115 min. of exposure to noise. Rank order correlations were computed between the hearing loss of the better ear after exposure to noise (A.M.A. computational procedure) and scores on the post-noise binaural pulse tests. The 500 c.p.s. tone and the white-noise tests were selected as yielding fair indications of the extent of noise-induced threshold shifts among the experimental subjects. These two tests were refined with respect to presentation and method of response and subjected to more detailed study.

Both tests were extended to 10 levels (2 db steps) and were recorded in six forms for series of different numbers of pulses. The groups of pulses were recorded in descending order of sound pressure level, with the highest level of output to the service headset (designated either ANB-1 or PDR-3 earphone) being 3.6 millivolts.

Directions for the test were not recorded, but were given orally to each group just before administration of the test.

> You will hear a number of beeps or pulses or bursts of sound. These occur in groups. Write down the number of beeps that you hear in each group. All you need to know is that the up-and-down spaces on this answer sheet are called <u>columns</u> and the left-to-right spaces, <u>rows</u>. You will go across the page two times each time the test is given. Listen carefully; keep perfectly quiet. Put on your headsets.

The recordings included an announcer's voice recorded at a constant level that paced the test.

> Stand by for test one: row one, column one ..., column two ..., column three ..., ... column ten ...; stand by for row two: column one ..., column two ..., ... column ten ...

The speech-to-signal ratio at the highest stimulus level was 5 db. Precision of timing was accomplished by editing and splicing the tape. A cathode-ray oscillograph indicated that no pre-signal transients that approached signal level were introduced by this process. Administration time for the test was 64 sec.

Part I

PROCEDURES AND RESULTS: Hearing Loss with Noise

Seven groups of experimental subjects were exposed to 110 db of noise. Each group of 12 male naval pilot or technical training personnel was sub-divided: four members wore no headset; four members wore a headset with earphones over both ears; and four wore a headset cocked on the head in a manner to cover or protect only one ear. Thus, there were 28 subjects in each of the three conditions. The testing occurred in a sound-treated and acoustically isolated room that had a minimum noise level of 27 db (General Radio meter, A scale) and an isolation attenuation of 55 db. The room contained interphone stations with headsets and tablet armchairs, and the loud-speakers of a system that generated aircraft-type noise up to 132 db.

An experimental session lasted 137 min. The session began with administrations of the pulse test, one for practice and one for a pre-noise score. Then the listeners sat in 110 db of aircraft-type noise (Harvard generator) for 120 min. The subjects who wore headsets heard and responded to two listening tests (word reception) during each 15 min. of the session. At the end of a 15-min. period the noise was turned off for 64 sec. during which time all of the subjects wore headsets and took the pulse test. Subsequent to the two-hour (less seven 64-sec. interruptions for testing) exposure to noise the subjects took the pulse test five times at three-min. intervals during a 15-min. terminal "quiet" period.

The data for each condition of exposure to noise were analyzed separately in a triple analysis of variance. These analyses are summarized in Table 1. The mean number of errors that attended each administration of the test is indicated in Table 2 and is plotted in Figure 1.

The analyses of variance (V) that are summarized in Table 1 show:

1. Successive administrations of the test yielded different scores (V_T/V_{TxS}).
2. The two types of pulses were not reacted to alike by different listeners (V_{PxS}/V_{TxPxS}).
3. The two types of pulses showed highly significant differences in mean values in the no-headset condition (V_P/V_{PxS}).
4. The two types of pulses were responded to dissimilarly through successive trials in the one-headset condition (V_{TxP}/V_{TxPxS}).
5. There were differences of scores among listeners.

The arrays of mean values in Table 2 somewhat explain the analyses of Table 1. Considered together the two tables indicate that 1. The test measured a threshold shift among the subjects with exposure to noise and a subsequent recovery. 2. The test showed the "recovered" hearing to be superior to the "original" hearing. This is interpreted to mean that the listeners were more practiced or "test-wise" at the conclusion of the experimental period than at the outset. Thus, greater familiarity or practice with the test before making experimental measurements is indicated. 3. Under an assumption that the final scores of Table 2 were better indications of the mean detection threshold of the listeners than were the initial scores, the mean loss of hearing that attended exposure to noise when at least one ear was protected by an earphone was approximately 1.5 steps on the test or approximately 3 db. With both ears exposed, the loss was greater, as much as 2.8 steps or approximately 5.6 db (noise). (This assumption discounts the possibility that the mean state of hearing was temporarily improved by recovery from the noise experience.) 4. The test yielded greater values of threshold shift when two ears were exposed

and greater shifts when one was exposed than when neither was "open." This was to be expected and is interpreted to relate to the validity of the test. 5. The threshold shift in the no-headset condition as measured by the pulses of noise was significantly greater than the shift measured by the 500 c.p.s. pulses. This result was peculiar to the condition and is interpreted as assurance that the two parts of the test do not measure the same aspect of the hearing function. Further assurance of this arises from the observation that the two signals are responded to differently when they are conveyed by dissimilar equipments. This fact is exploited in the testing of alternative headsets. For example;

	Headset 1	Headset 2
500-cps pulses	56.2	55.1
White-noise pulses	69.3	42.6

The values are percent correct scores. In other words, the two headsets were similar in the capacity to transmit the tone pulses but differed in their capacity to convey the noise pulses audibly (N, subjects, 24). One import of this result is that while pooled scores of the two parts of the test may have some value, separate scores must also be computed. In the course of these studies Hirsh and Ward (5) reported substantial bounces in the auditory threshold after exposure to tone and noise. It is noted that the mean error score for both types of pulse increased in the "headset" condition between the end-of-noise measure and the 3-min. post-noise measure.

The significant interaction between trials and type of pulse in Table 1 appears in Figure 1 as a crossing and re-crossing of the two plots. There is no present explanation for this result. Nor is there any explanation for the anamalous fact that listeners who wore a headset throughout made more errors than the listeners who had one ear protected with one earphone. However, this result is in keeping with data that are being accumulated by Dr. John J. O'Neill (Ohio State University), which seem to indicate that noise fed to one ear apparently improves the subsequent acuity of the contralateral ear.

A PRACTICE EFFECT WITH THE TEST

One indication in the preceding results was that listeners tended to improve their scores with repeated experiences with the tests. This was suggested through the circumstance that final scores were lower than initial error scores. To quantify this effect 10 groups of 12 experimental subjects each, all NROTC personnel, were given the test 15 times. There were 11 panels; however, panel 11 repeated the test 10 times instead of 15 and is not included in the present treatment. The successive administrations to a single group were without interruption. The position of a listener's headset (HS-33) was not altered during or between the tests. The 10 panels were tested on successive working days. The mean numbers of right scores for the repeated tests are enumerated in Table 3 and entered graphically in Figure 2. These values are the mean responses of 10 panels.

The data were arranged in a matrix for a triple analysis of variance with columns representing successive trials; sub-columns, noise and tone; rows, panels. The mean score of each panel on each portion of the test was entered as a basic measure for the analysis. The results of the analysis, summarized in the first column of Table 4, showed that an assumption of "no difference" among the mean scores on successive trials could be rejected. Figure 2 suggests that the scores subsequent to Trial 5 might be the same. Relevant tests are described in the next section.

The immediate significance of the effect of practice on the scores of the test is the implication that experimental subjects must be administered the pulse test at least five times as an indoctrination exercise before a first experimental measure is obtained in a session. Six forms of the test (different programming of the numbers of pulses) make this feasible. This result applies when a group of subjects yields a single score. (It might obtain also in clinical situations where a pulse-type test is often employed as a screening device to detect individuals with a hearing loss; also in selections tests--see Part II.)

RELIABILITY OF THE TEST

The analysis that is summarized in column 1 of Table 4 prompts questions about the reliability of the pulse test. In view of the fact that the two types of pulses relate to different aspects of the hearing function, no attempt was made to equate exactly the responses to the noise and tone portions of the test; thus the significant difference that is indicated in Table 4 between the sets of scores for the noise and tone portions was expected. The mean difference between the two scores is approximately 1.5 scale units (of 10). As discussed above, a practice effect was known to operate among the early successive administrations--possibly the first five--of the test; thus significant variance in connection with trials, as shown in column 1 of Table 4, was anticipated. The disquieting features of the analysis that is summarized in column 1 of Table 4 were the significant variances attributable to 1. panels and 2. the interaction between panels and noise-tone. When the data were viewed with these two apparent anomalies in mind, it was noted that the first three panels responded inconsistently with the remaining seven panels. The earlier panels heard a higher proportion of the noise signals than tone signals: means, 3.2 and 2.3 respectively. The remaining panels identified the tone signals the more frequently: means, 3.0 and 4.4 respectively. This latter relationship is in line with subsequent experience when the test is taken before the listeners are exposed to noise. Under an assumption that some experimental error occurred in the administration of the test to panels 1-3, the data pertaining to these panels were arbitrarily removed from the matrix and a second analysis performed. This analysis is summarized in column 2 of Table 4. The "selected" data continued to exhibit, in lesser degree, the erratic characteristics of the more complete analysis. Data were further "selected" so as to remove some of the variance presumably attributable to inexperience by eliminating Trials 1-5 for all panels. The analysis of the remaining data is summarized in the right-hand column of Table 4. This analysis was more reassuring. It indicated that for a single panel the mean scores among successive trials did not vary significantly if the results of the first five trials were considered to be indoctrination and not included in the analysis. This stage of "selection" of the matrix also reduced the interaction variance between panels and noise-tone to approximately a chance occurrence. It left, however, the obvious implication that panels (successive days) were responding to the test differently. The respective means for the trials and panels under discussion follow:

Trials Based on Mean Correct Scores for Panels 4-10

A.	Trial	6	7	8	9	10	11	12	13	14	15
	Tone	4.9	4.8	4.5	5.1	4.6	5.1	4.6	4.6	5.0	4.3
	Noise	3.1	2.9	3.3	3.5	3.9	3.4	3.2	3.1	3.6	3.4

Panels Based on Mean Correct Scores for Trials 6-15

B.	Panel	4	5	6	7	8	9	10
	Tone	5.5	6.3	5.7	7.3	7.3	7.7	6.6
	Noise	3.1	3.8	4.1	4.2	5.1	5.4	5.5

The data of Table 4 are reassuring throughout in the small fraction of the total variance that was unsystematic and not accounted for by the three double analyses that were subtended by each triple analysis. This implied the possibility that each time the test was used it was operating reasonably well. Uncontrolled factors apparently lay in the administration of the test. It remained to locate the source of these differences.

As a further inquiry into the "behavior" of the pulse test, a single panel of nine members took the test 12 times on each of seven successive days. An analysis of the data from this panel was performed in the manner described immediately above in connection with the responses of the ten panels. These tests were to explore specifically whether or not indoctrination presentations of the materials of the test were indicated even with sophisticated panels, and whether panels of listeners on separate administrations of the test (days) accounted for the significant variations among panels in the analyses of Table 4. The results of the analyses of the administrations to the same panel are summarized in Table 5. The pertinent mean correct score follow:

Trials Based on Mean Correct Scores for Days 1-7

Trial:	1	2	3	4	5	6	7	8	9	10	11	12	
Tone	5.1	6.3	6.6	6.3	5.9	7.2	7.1	7.0	7.5	8.6	6.4	7.0	.84
Noise	5.2	5.2	4.5	5.6	5.2	5.5	5.6	5.8	6.2	6.2	5.6	6.0	.46

Days Based on Mean Correct Scores for Trials 1-12

Day	1	2	3	4	5	6	7
Tone	6.9	5.9	6.6	8.4	6.4	6.1	5.9
Noise	5.6	4.8	5.4	7.2	6.5	5.0	4.9

These mean values in conjunction with the analyses of Table 5 (V_D) indicate that the test remained somewhat out of control insofar as yielding comparable scores from one series of administrations to another (days). The extreme deviation occurred between the presentations on Day 4 (high) and on Days 2 and 7 (low). The differences among the scores for these days were equivalent to approximately five db changes in signal level (2.5 test units @ 2 db/unit). The mean fluctuation was 0.6 signal unit and the r.m.s. value slightly less than 1.0 unit.

The analyses of Table 5 indicated that indoctrination presentations of the test were essential daily even with practiced listeners. In this regard, the difficulty arose in identifying tone, and noise (see V for tone and noise separately, Table 5).

The tests cited above extended beyond the original purpose of the development of the pulse tests as in instrument for determining threshold shift as a result of exposure to noise. First, the statistically significant fluctuations of the observed scores were within the inherent step-adjustments of clinical audiometers (5 db). Second, the test operated systematically within a single experimental session. For example, a rank order correlation between the panel scores for tone and noise, day by day, was rho = .88. Since the measurement of the threshold shift in terms relative to the mean state of hearing of a panel at the outset of an experimental session was to be under observation, the test might be viewed as within satisfactory limits of tolerance, provided the panels of listeners become practiced in each session in making the identifications that the test requires. Beyond the immediate objective, however, lay the more

far-reaching question of the reliability of a group pulse-type test and particularly one that is administered from recorded signals.

Anderson (1) employed a recorded pulse-type test to screen the hearing of entering university students. The procedure is common. He found that more than half of the ears that did not respond to the 15 db screening level (single presentation) were "normal" when retested under laboratory conditions. In view of the present results this finding might be attributed to "no indoctrination through practice."

THE ADEQUACY OF A DUAL SIGNAL TEST

Little can be postulated about the validity of the present pulse test. An alternative type of material would be a click, possibly filtered in different manners and presented at varying levels. The present materials were selected as correlating with the audiograms (percent hearing loss) of normal hearing subjects, exposed to noise for two hours. Subsequently an experimental procedure indicated that subjects who had been exposed to the same noise with differing amounts of protection responded to the two portions of the test differentially.

Anderson (1) employed the test in an evaluation of another pulse-type test and found that both portions of the present test were related on a statistically significant basis (when given as monaural administrations to male university students who had failed one test of hearing) with scores obtained by pure-tone audiometry, 500—4000 c.p.s. (N, 119 subjects, 238 ears). However, the relationship was "stronger" between the 500 c.p.s. tone and the lower frequencies on the audiometer and between the white noise portion of the pulse test and the higher frequencies that he tested. Scores on the white-noise portion of the test related significantly to scores on the spondee speech reception test; scores on the tone portion did not. This was another indication that the two types of stimulus material sample different aspects of the hearing function. However, other or additional stimulus signals might be equally or more differentiating.

RESPONSES <u>vs</u>. LEVEL

A further consideration in an evaluation of the pulse test is the effect of the sound pressure level of the signal upon the proportion of correct responses. The responses to the individual items (in sound pressure level units) of the 15 administrations of the test to 10 panels, described above, were plotted. Figure 3 is a composite cumulative graph that represents the responses of 120-132 listeners who heard the test 15 times. This plot indicates that nearly 90% of the responses to the highest level of the test were correct. Had only the responses to trials 6-15 been considered the value would have exceeded 90%. The remaining 10% includes incorrect responses from all causes: equipment failure, inadequate instructions, 'lost' on the test, indisposition, etc. The data that are summarized in Figure 3 were treated by an analysis of variance preliminary to testing both sets of means of Figure 3 for linearity by Lindquist's Case 4 (7). The preliminary analysis is summarized in Table 6. An assumption of linearity was not rejected in the instance of the responses to <u>tone</u> (F, 1.31; 8 and 81 degrees of freedom); however, by the same test an assumption of linearity in the of the responses to <u>noise</u> was rejected (F, 9.90; 8 and 81 d.f.). Degrees of freedom (d.f.) in this test are determined by conditions (levels) <u>minus</u> 2 (or 10 -2 = 8), and the <u>remainder</u> term from a test of "no difference" among the means of the scores for conditions, i.e., levels x panels = 9 x 9 = 81. A hypothesis of linearity was tenable when the responses to the two lowest levels (-18 and -16) were excluded from the analysis.

The curves in Figure 3 are similar in form to the individual plots (not shown) of the responses to the 15 trials that contributed to Figure 3 except that the ceiling in Figure 3 is attenuated by the limited ranges of Trials 1-5. The curves, separated horizontially by 2-2.5 db throughout the greater part of their growth, converge at the

highest sound pressure level, and show an attenuated rate of decay in mean listener scores near the point of 'no detection' in the case of noise.

The tests were sensitive to the sound pressure level of tone and noise and within the range of 18 db elicited in excess of 75% of the total possible range of responses (0-100%).

In the region of threshold (50 percent correct responses) the effect of a shift of 2 db in the level of the tone or noise signal was 10-15% identification (found by reading in percent the difference between successive points of measurement on the same curve in Figure 3). This, in turn, approximates the difference, near the midrange of the curves, between the proportion of correct responses to tone and to noise signals at the same level of attenuation (read in percent the differences between points of measurement on the two curves at the same level of attenuation in Figure 3).

There are various ways in which measurements that are obtained by the pulse test might be presented. Mean number of errors, mean number of correct responses, and percentage of correct scores are presented in Figures 1, 2, and 3 respectively. Tentatively, the item-by-item score of a panel is computed as well and the scores are viewed in terms of the relative pressure level of the pulses at threshold (50% correct score). Since numbers of errors, percentages, etc., are meaningful only in terms of the testing instrument and the singular condition of administration, and since a test is typically most sensitive in its midrange, threshold (db) appears to be a promising unit in which to describe "shift", and to be a unit that accommodates both convention and "transfer" of the findings. A summary of the data of Table 2 and Figure 1, converted to identification threshold, appears in Table 7. The data of Table 2 are subject to the limitation that only one test for indoctrination or practice was administered. Since subsequently at least five practice tests were found to be necessary, the first test that was included in the data of Table 7 was the one administered sixth, i.e. 60 minutes.

An alternative manner of presenting measures is provided in the following example. Eleven panels, each of 12 listeners, took the pulse test two times at the outset of experimental sessions, the first time as practice. The panels then 1. participated in intelligibility testing under 110 db of simulated aircraft noise, propeller type, for 30 minutes, 2. were re-tested with the pulse test, 3. sat in quiet for three minutes, 4. participated in a second 30-minute period of intelligibility testing, and 5. were readministered the pulse test. The objects of this procedure were to find whether the pulse test was sensitive to changes in hearing brought about by exposure to noise of 30 minutes, (if so) whether three minutes might suffice for recovery, and (if not) whether a second exposure of like duration produced a cumulative effect. The successive mean correct scores were:

	Mean Right Responses per S per group	
Test	Tone	Noise
1. Practice test	-	-
2. Pre-test	3.30	2.75
3. 30-minute test	2.57	1.47
4. Post 3-minute silence	2.67	1.45
5. Second 30-minute test	2.66	1.88

The data were arranged in a matrix with panels of subjects as rows and Tests 2-5 as

columns. Basic measures were mean correct responses per person. The variance ratio for tests as shown in Table 8 was highly significant. All scores subsequent to the pre-test were significantly lower than pre-test scores - this in spite of the fact that "learning," or the practice effect, was continuing throughout the final (fifth) administration. (The necessity for five indoctrination trials had not then been established.) The contrary influences of practice and of the effect of noise are confounded in the results that are summarized in Table 8. (Also the variability of scores among panels that was discussed above is noted again in Table 8.) A modified treatment of the results of the pulse test was tried with these data, in part to cope with panel variability. From 80 to 90 percent of the subjects who took the test had a cut-off level above which they made all responses correctly, and below which none were correct. The median level of the cut-off item for a panel might be converted readily into signal level through Figure 3. The median value for several panels would be expected to be stable and to provide a reference value to which deviant panels might be adjusted. In the present data the means cited above were in close agreement with the medians of the cut-off scores, panel by panel. For example, the apparent decrements in hearing in the data cited immediately above for the first 30 min. of exposure to noise were: tone 0.7, and noise 1.3 score units, or 1.4 and 2.6 db respectively. In units of threshold decrements (described above) the differences were 1.0 and 1.5 gross score units or 2.0 and 3.0 db. The comparable estimates, determined by the median cut-off scores of the subjects within a panel and, in turn, by the median of the panels, were 1.9 and 2.8 db.

The "median of the individual cut-offs," when applied to the repeated measures of the panel that took the test 12 times on seven days (above), yielded results that were in substantial agreement with the computed mean correct scores. However, the value of trial variability was apparently augmented through the use of medians. The standard deviation of the tone scores was increased from .40 to .70, and of the noise scores from .46 to .58 Medians:

Trials, based on Days 1-7

Trial	1	2	3	4	5	6	7	8	9	10	11	12	SD
Tone	6	7	7	6.3	6.5	8	7.5	7.5	8	7.5	8	8	.70
Noise	5.3	5	5.5	6	4.7	6	6	6.3	6	7	6	6	.58

Days, based on Trials 6-12

Days	1	2	3	4	5	6	7
Tone	7.7	6.2	8	9	8	7.5	7
Noise	6	5.5	6	8	7	5	6

Both treatments, means and cut-off medians, indicated that successive administrations of the test, beyond the fifth, were stable for a panel of listeners, once the test was set in operation for the experimental session.

SUMMARY (Part I)

A pulse-type test has been devised for obtaining from a panel of experimental subjects, within one minute, an approximation of the amount of temporary hearing loss that has been occasioned by exposure to noise. The test includes tape-recorded pulses of 500 c.p.s. and white noise, both presented in 10 successive steps of 2 db decrements - a range of 18 db.

1. The two portions of the test appear to appraise different aspects of the hearing function and to be sensitive to effects that the test was designed to measure.

2. Five administrations of the test are required before reliable measurements can be obtained from a group of experimental subjects.

3. The principal difficulty that is encountered with the test is the securing of stable results from one experimental session to another. This difficulty presumably lies in the control of sound pressure level, i.e., in the playback instrumentation, including the methods used to check session-to-session presentations.

Part II, (following) of this report may be considered a further step in the evaluation of the pulse test, and relative to 3 (immediately above) implies that the requirements for "playback" may exceed the limits of tape-recorder reproduction.

Part II

A Pulse Test in Screening and Selection

As explained in Part I, the recorded pulse-type test was devised to evaluate an effect on hearing of the exposure of ears to high-level noise. This measurement, in turn, was for expediency limited to two signals (not the typical sampling of audible frequencies): 500 c.p.s. and white noise. The U. S. Navy Bureau of Medicine and Surgery announced an evaluation of hearing tests foi selection and screening purposes at Camp Lejeune, North Carolina, and invited the Naval School of Aviation Medicine to participate with the pulse test. The invitation was accepted with an explanation that although the test was probably not appropriate to this application, the data from comparison tests would be helpful in appraising the properties of the pulse test. Also, for purposes of comparison the pulse test was coupled with a multiple-choice word reception test. The latter was extracted from Form C of the multiple-choice intelligibility test series (3). Two answer forms were prepared, illustrated in Figures 4 and 5.

Form 1 of the answer sheets was prepared for one ear and Form 2 for the other ear. The pulse test itself was also adapted. It was reduced to nine decremental steps instead of ten (to accommodate the nine groupings of words of the word-reception test); the steps were of four db instead of two; and of principal importance, the test was for monaural administration instead of binaural. Six orders of the pulse presentations were prepared. These were interspersed on a magnetic tape recording between the six successive word lists. The words were read (recorded) by one voice; and within each "block" or set of nine 3-word groups, the successive groups of words were equated in sound pressure level with the nine steps of the pulses. Thus successive groups of words represented a series of four-db decrements. The entire test (two forms) required 25 minutes for administration. The equipment for administering the test included a magnetic tape playback unit (Stancil Hoffman) and headsets (monaural, PDR-3) for 25 listeners. Playback level was set relative to a 1000 c.p.s. tone recorded on each test. In practice, because of "time limits" three tests instead of six were administered to each ear of the experimental subjects, and alternate Forms 1 or 2 was used at the discretion of the operator, who attempted to employ the two forms approximately the same number of times.

Other tests that were included in the battery of Camp Lejeune test were 1. the "New London test," 2. the "Glorig test," and 3. an audiometric threshold test. The answer sheets from all of the test were obtained by the Acoustic Laboratory after on-the-spot evaluation was made, and with the help of the Psychology Laboratory of the School of Aviation Medicine, the test were compared.[1] All data were entered on IBM

---

[1] The analyses and computations that follow were made by LCDR Woodbury Johnson of the Aviation Psychology Laboratory of the Naval School of Aviation Medicine.

cards. Computations, except for final steps, were performed on IBM equipment.

It is note worthy that all of the tests, except the standard audiometric one, relied on recognition and summation of pulses on the part of the listeners. The Glorig test is a series of groups of pure-tone pulses of varying frequencies. This test is distinguished by automatic programming. A visual altering signal indicates where to enter such experience on the answer sheet. Both ears are tested monaurally in one administration of the test, and the tests sample the frequencies of the speech range.

The New London test is a presentation of pulses in a pre-set sequence from an audiometer, manually controlled.

The pure-tone audiometric test is, of course, standard.

Both the Glorig and the New London tests yielded arbitrary pass-fail scores. With the Glorig test, as administered, the individual passed or failed; with the New London test each ear passed or failed. One interpretation from the pure-tone audiometric test was a calculated "hearing-loss" score for each ear according to the weightings and averaging procedures of the American Medical Association (except that these computations are normally applied only to the "better ear").

Form 1 was administered to 190 persons; Form 2, to 297. The three variables or stimuli of the test were scored separately for each ear, both total "right" score and a "cut-off" score for each "block" (see Figure 4). The "cut-off" score was the "last item right" within a "block" in the instance of tone, and noise and was the last item within a list to have two of the three words right in the instance of word reception. The scores for a block were summated through three blocks to yield a score for an ear.

The mean values for the right and cut-off scores are enumerated separately by ears and for Forms 1 and 2 (both separately and combined) in Table 9. The maximum possible value for noise and tone was 27 and for words, 81. Since the subjects had "normal" hearing the AMA scores have limited meaning, as this scoring procedure assumes a hearing loss of some proportion, possibly 25, 40, or 50% in at least one ear. Thus scores that average 4 and 5% would be in the tail of the distributions that gave rise to the procedure.

The data were treated with correlation techniques. The results are summarized in Tables 10-11. The entries in Table 10 are uniformly highly significant statistically except for some of the correlations involving the AMA scores. Correlations of .95 - .99 between "score" and "cut-off" indicate that they were equally good indices of performance in appraising the reception of pulses of noise and tone. In the instance of words, however, score correlated numerically higher with the other obtained measures than did cut-off.

The correlations pertaining to the left ear tended to be numerically higher than those related to the right ear. This difference was statistically significant in measures that derived from words. Since the left ear was always tested second the assumption is made that learning occurred during the administration of the test, and that either word reception per se improved or that instructions were followed more correctly during what amounted to the second half of the test than during the first half.

The entries of Table 10 show that the correlations that related to Form 1 were numerically (and frequently significantly) higher than the comparable measure relative to Form 2. Table 9 shows also that the mean scores attending Form 2 were numerically

higher than those of Form 1. A check of the recordings with the Sound Apparatus Co. power level recorder and Audio Devices Logger revealed that the signal-reference tone ratio was apparently 0.7 db greater in Form 2 than Form 1. (This "error" checks in magnitude with values of Figure 3, and implies that the diurnal variations in the scores of Part I of this report are within the operating efficiency of tape reproducers and panel meters.)

In view of the foregoing discussion, the evaluation of the pulse test might be based on the more representative values that were obtained in these trials, on <u>scores</u> (not "<u>cut-off</u>"), <u>Form</u> 1 (not <u>Form</u> 2), and <u>left</u> ear (not <u>right</u>). These three values are underlined in Table 2. Specifically, <u>tone</u> correlates with <u>noise</u> and <u>words</u>, respectively, .75 and .68; <u>noise</u> correlates with <u>words</u> ..78. The correlations with <u>words</u> are believed to be higher than have been reported previously (1).

Table 11 presents correlations between the scores of the two ears of the same listener. These values were presumably attenuated by the discrepancy between <u>ears</u> that appeared in Table 10. Inasmuch as the two ears of a listener are commonly dissimilar, the values cannot be regarded as a set of "split-half" correlations. It may be noteworthy that the highest correlations pertain to word reception scores between the two ears--a test that might relate to intelligence, educational achievement, etc. However, in like manner it is apparent that in each column the highest pair of correlations is associated with the two <u>row</u> headings that are like the <u>column</u> heading. Thus, tone "<u>score</u>" in one ear correlates highest with tone "score" and "cut-off" in the other; noise "<u>score</u>" and "<u>cut-off</u>" etc. This might indicate that the identification of a signal of a particular type is an individual skill.

The only attempt that was made to correlate the test under discussion with the audiograms of the subjects was through the AMA interpretation of the audiogram. These correlations appear in Tables 10 and 11. The generally low values are possibly attributable to the limited range of the AMA scores, explained above. There is the contrary observation, however, that the AMA scores of the two ears correlated .62. This significant correlation might indicate that the AMA scores were more valid than this discussion would indicate.

The various measures that were obtained for the two ears were correlated through biserial correlation with the arbitrary <u>pass-fail</u> categories of the Glorig test, N = 486. The correlations were low, but were statistically significant, under the assumption that $\underline{r}$ bis = $\underline{r}$. The higher correlations were again associated with the <u>left</u> or the more practiced ear.

	Tone Score	Tone "Cut off"	Noise Score	Noise "Cut off"	Words Score	Words "Cut off"
Right ear	.17	.18	.26	.26	.21	.19
Left ear	.24	.23	.30	.30	.25	.24

These same measures were correlated biserially with the pass-fail categories of the New London test for each ear, N = 489. Again, under an assumption of equality of $\underline{r}$ and $\underline{r}$ bis all of the correlations were significant with the possible exception of <u>tone</u> in the right ear. These correlations were uniformly higher with the <u>left</u> ear than with the <u>right</u> ear. In this instance two "practice" effects may have operated. In both tests the right ear was tested first. The relative reliability between measures of the "first ear" and "second ear" in "quick" audiometry may be reflected in the statistically significant difference between the "right ear-right ear" and the "left ear-left ear" values (immediately above) relative to <u>tone</u>.

	Tone Score L	Tone Score R	Tone "Cut off" L	Tone "Cut off" R	Noise Score L	Noise Score R	Noise "Cut off" L	Noise "Cut off" R	Words Score L	Words Score R	Words "Cut off" L	Words "Cut off" R
Right ear (New London)	.21	.08	.19	.08	.35	.28	.35	.29	.26	.24	.25	.20
Left ear (New London)	.24	.14	.23	.13	.38	.28	.39	.27	.27	.21	.26	.16

The two sets of correlations cited above, "pulse test vs. Glorig" and "pulse test vs. New London," are of the same order of magnitude. This was not to be expected. The Glorig pass-fail scores were determined binaurally, and the pulse-test scores monaurally. The former would yield the same result irrespective of which ear was "poor." This would be expected to attenuate the correlation coefficient in a comparison with a monaural test. The New London "pass-fail" scores were monaural scores. Thus the "pulse test vs. New London" correlations were based on the same ears.

A tetrachoric correlation was performed on the binaural pass-fail Glorig scores and the monaural pass-fail New London scores. These correlations were, r tet = .65 and .49 for the right and left ears respectively (N, 486). Both values were of a higher order of magnitude than the similar correlation of these tests with the pulse test.

SUMMARY (Part II)

The pulse test was modified and coupled with a word reception test in a manner to permit 12 administrations. Six of these were designated Form 1, and the remaining ones Form 2. The fact that in the construction of the forms a difference of 0.7 db occurred between the level of the reference tone and sound pressure level of the test items was apparent in the scores that the two forms yielded.

Alternative procedures of scoring the pulse test, "cut-off scores" vs. "right scores," did not yield different results.

The scores for the ear that was tested second were higher than for the ear tested first.

Thus, the most representative scores of the test were assumed to be 1. number right (tone, noise, words), 2. practiced ear, 3. Form 1 (the higher level by 0.7 db). These scores correlated with each other, r .68 - .78.

Comparison pulse-type tests that sampled the frequencies of the speech range correlated with each other, r tet .49 and .65, and with the present pulse-word test, r bis .24 - .38.

The merit of the present pulse-word test as a selection device depends upon the value assigned the present word-reception test as a criterion measure.

Table 1. Summary of three analyses of variance of error scores of listeners who heard the pulse test 1. before, 2. at intervals during, and 3. after exposure to 120 min. of noise. Basic measure: number of errors (of a possible 10) made by one listener when responding to one type of pulse in an administration of the test. N, subjects, 28 who wore no headsets in noise, 28 who wore one earphone, 28 who wore two earphones.

		Variance		
Source of variation	d.f.*	Headset	One earphone	No headset
Trials (T)	13	11.1**	16.3**	26.5**
Type of pulse (P)	1	8.0	8.0	249.0**
Subjects (S)	27	123.5**	83.8**	97.9**
T x P	13	.7	27.9**	5.2
T x S	351	2.2	2.6**	3.1
P x S	27	25.5**	20.8**	7.1**
T x P x S	351	1.2	.5	3.1

* degrees of freedom.

** F, significant at the one percent level of confidence.

Table 2. Mean number of errors (of possible 10) made by 28 listeners in each of 14 administrations of 500 c.p.s. and white-noise portions of the pulse test. Three conditions of ear protection.

		Headset Conditions								
		Headset			One Earphone			No Headset		
Test No.	Time (Min.)	Noise	Tone	Mean	Noise	Tone	Mean	Noise	Tone	Mean
1	0*	5.11	4.74	4.93	3.83	3.97	3.90	3.69	4.31	4.00
2	15	4.70	5.11	4.91	3.69	3.72	3.71	5.28	3.79	4.54
3	30	5.07	5.19	5.13	4.45	4.00	4.23	5.38	3.79	4.59
4	45	4.96	4.78	4.87	4.34	3.62	3.99	5.45	3.93	4.69
5	60	5.07	5.30	5.19	4.45	4.07	4.26	5.90	4.59	5.24
6	75	5.19	5.67	5.43	4.21	4.21	4.21	5.38	4.31	4.85
7	90	5.26	5.63	5.45	4.38	4.38	4.38	5.72	4.79	5.26
8	105	5.81	6.11	5.97	4.79	5.07	4.93	6.07	4.90	5.49
9	120**	5.59	5.85	5.72	4.66	4.45	4.55	6.79	4.86	5.83
10	123	5.78	6.22	6.00	4.59	4.31	4.45	5.83	4.72	5.28
11	126	5.22	5.37	5.30	3.69	3.07	3.38	5.10	3.79	4.45
12	129	5.00	5.19	5.10	3.31	3.31	3.31	4.59	3.86	4.23
13	132	4.56	4.74	4.65	3.55	3.52	3.54	4.34	3.10	3.73
14	135	4.37	4.67	4.52	3.38	2.83	3.11	3.93	3.17	3.55

* pre-noise; one practice test preceded this.

**end of noise

Table 3. Mean number of correct responses (of a possible 10) to the noise and tone portions of the pulse test in 15 successive trials. N, subjects, 132 (trials 1-10); 120 (trials 11-15).

Trial	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tone	1.9	2.9	3.6	3.6	3.7	4.1	3.9	3.7	4.3	4.1	4.4	4.1	3.9	4.3	3.8
Noise	1.3	2.4	2.9	2.6	3.0	3.2	3.3	3.4	3.5	3.2	3.4	3.4	3.1	3.6	3.5

Table 4. Summaries of analyses of variance of the mean scores of panels of listeners on the noise and tone portions of the pulse test on repeated trials. Degrees of freedom (d.f.), shown in parentheses after variance (V), indicate sucessive stages in "selecting" data.

Source of variation	Variance: 10 panels; trials 1-15	Variance: 7 panels; trials 1-15	Variance: 7 panels; trials 6-15
Trials (T)	7.27(14)**	5.43(14)**	.52(9)
Panels (P)	24.36(9)**	8.59(6)**	5.95(6)**
Noise-Tone (NT)	41.74(1)**	110.02(1)**	80.26(1)**
T x P	.04(126)	.23(84)	.27(54)
T x NT	.21(14)	.36(14)	.33(9)
P x NT	11.47(9)**	1.43(6)**	.83(6)*
T x P x NT	.41(126)	.25(84)	.36(54)

**F, significant at the 1% level of confidence.

* F, approximately at the 5% level of confidence.

Table 5. Summaries of analyses of variance of scores on the pulse test of one panel of nine listeners, on each of seven days. Total scores, noise scores, and tone scores analyzed separately.

Source of variation	d.f.	Variance: Entire test	Tone only	Noise only
Days (D)	6	18.13**	9.64**	9.90**
Repetitions (R)	11	3.15**	2.99**	.95
Noise-Tone (NT)	1	39.34**		
D x R	66	1.05	.88	.55
D x NT	6	1.42		
R x NT	11	.80		
D x R x NT	66	.38		

** F, significant at the 1% level of confidence.

Table 6. Summary of an analysis of variance of the scores obtained on two portions of the pulse test at 10 levels (see Figure 3 for relevant means). N, 120-132; 15 trials.

Source of variation	d.f.	Variance
Noise-Tone	1	9856.08**
Levels	9	50505.60**
Remainder	9	625.51

**F, significant at the one percent level of confidence.

Table 7. Threshold (50 percent identification) in db during and after exposure to noise for 120 minutes.

Headset condition	The incremental step from the minimum level of the test, at which a panel identified an item 50% correctly, at minute:				Corresponding relative level of threshold (db from maximum signal), at minute:			
No headset	0	60	120	135	0	60	120	135
Tone	-	6.0	7.5	4	-	-6	-3	-10
Noise	-	4.5	4.8	3.6	-	-9.0	-8.4	-10.8
One earphone								
Tone	-	3.7	4.6	3.1	-	-10.6	-8.8	-11.8
Noise	-	4.0	4.7	3.0	-	-10.0	-8.6	-12.0
Two earphones								
Tone	-	5.0	5.5	3.7	-	-8.0	-7.0	-10.6
Noise	-	4.7	6.0	3.3	-	-8.6	-6.0	-11.4

Table 8. Summary of an analysis of variance of the mean responses of 11 panels of listeners to four administrations of the pulse test interspersed with noise.

Source of variation	d.f.	Variance	
		Tone	Noise
Tests	3	1.21**	3.72**
Panels	10	3.38**	.77**
Remainder	30	.36	.22

**F, significant at the one percent level of confidence.

Table 9. Mean values and standard deviations (figures in parentheses) of scores yielded by Forms 1 and 2 of the pulse-type and multiple-choice word-reception tests.

	Form 1 N, 190	Form 2 N, 297	Combined N, 487
Right ear			
500 cps			
"Score"	13.18(4.81)	15.34(4.47)	14.50(4.72)
"Cut off"	14.15(4.81)	16.08(4.47)	15.32(4.70)
Noise			
"Score"	17.34(4.65)	18.52(4.30)	18.06(4.47)
"Cut off"	17.89(4.50)	19.03(4.22)	18.58(4.37)
Words			
"Score"	23.12(9.92)	25.26(10.21)	24.42(10.15)
"Cut off"	11.58(5.65)	12.09(5.30)	11.90(5.44)
AMA	4.84(6.99)	3.35(4.77)	3.93(5.78)
Left ear			
500 cps			
"Score"	13.52.(4.88)	15.44(4.28)	14.69(4.62)
"Cut off"	14.19(4.92)	16.00(4.20)	15.30(4.58)
Noise			
"Score"	16.66(5.08)	18.69(4.26)	17.90(4.70)
"Cut off"	17.05(4.99)	19.23(4.18)	18.38(4.63)
Words			
"Score"	26.73(11.94)	29.90(11.78)	28.66(11.95)
"Cut off"	12.54(5.58)	13.12(5.71)	12.89(5.67)
AMA	5.49(7.12)	4.43(5.98)	4.84(6.47)

Table 10. Correlation matrix among measures of the same ears, Form 1, Form 2, Forms 1-2 (from left to right within a group of three values).

	Tone "Score"	Tone "Cut-off"	Noise "Score"	Noise "Cut-off"	Words "Score"	Words "Cut-off"	AMA
Tone "Score"							
R	--- --- ---	.95 .96 .96	.77 .59 .68	.75 .57 .65	.56 .49 .52	.53 .49 .50	--.17 .02--.10
L	--- --- ---	.98 .97 .97	.75 .60 .68	.74 .61 .69	.68 .53 .60	.67 .53 .59	--.29--.14--.22
Tone "Cut off"							
R		--- --- ---	.72 .52 .61	.73 .51 .61	.51 .44 .48	.50 .43 .46	--.18 .01--.11
L		--- --- ---	.73 .58 .67	.74 .60 .68	.66 .50 .58	.66 .52 .57	--.30--.11--.21
Noise "Score"							
R			--- --- ---	.98 .96 .97	.70 .63 .66	.66 .58 .61	--.37--.19--.29
L			--- --- ---	.99 .97 .98	.78 .65 .71	.76 .63 .68	--.37--.32--.35
Noise "Cut off"							
R				--- --- ---	.68 .61 .64	.65 .57 .60	--.37--.21--.30
L				--- --- ---	.77 .65 .71	.76 .63 .68	--.38--.33--.36
Words "Score"							
R					--- --- ---	.84 .81 .82	--.36--.15--.26
L					--- --- ---	.87 .85 .85	--.32--.28--.30
Words "Cut off"							
R						--- --- ---	--.33--.07--.20
L						--- --- ---	--.33--.27--.30

Table 11. Correlation matrix among measures of pairs of ears, Form 1, Form 2, Forms 1-2 (from left to right within a group of three values).

	Tone "Score"	Tone "Cut off"	Noise "Score"	Noise "Cut off"	Words "Score"	Words "Cut off"	AMA
Tone "Score"	.68 .59 .64	.67 .55 .62	.54 .48 .52	.51 .46 .50	.47 .36 .42	.45 .32 .38	-.15-.03-.12
Tone "Cut off"	.67 .59 .64	.69 .57 .64	.54 .45 .50	.54 .44 .50	.47 .33 .40	.46 .31 .38	-.16-.10-.11
Noise "Score"	.59 .38 .50	.57 .35 .47	.68 .63 .66	.68 .61 .65	.58 .43 .50	.54 .35 .44	-.29-.19-.26
Noise "Cut off"	.59 .38 .50	.58 .35 .48	.69 .62 .66	.69 .62 .66	.58 .42 .50	.54 .34 .43	-.28-.20-.26
Words "Score"	.51 .39 .45	.48 .34 [illegible]	.57 .58 .59	.55 .55 .56	.73 .73 .74	.61 .56 .58	-.27-.17-.23
Words "Cut off"	.52 .41 .46	.52 .37 .43	.57 .56 .56	.56 .54 .55	.61 .60 .61	.57 .54 .55	-.27-.13-[illegible]
AMA	-.13 .01-.07	-.13 .03-.05	-.15-.16-.21	-.26-.15-.20	-.28-.09-.18	-.30-.06-.17	.62 .48 [illegible]

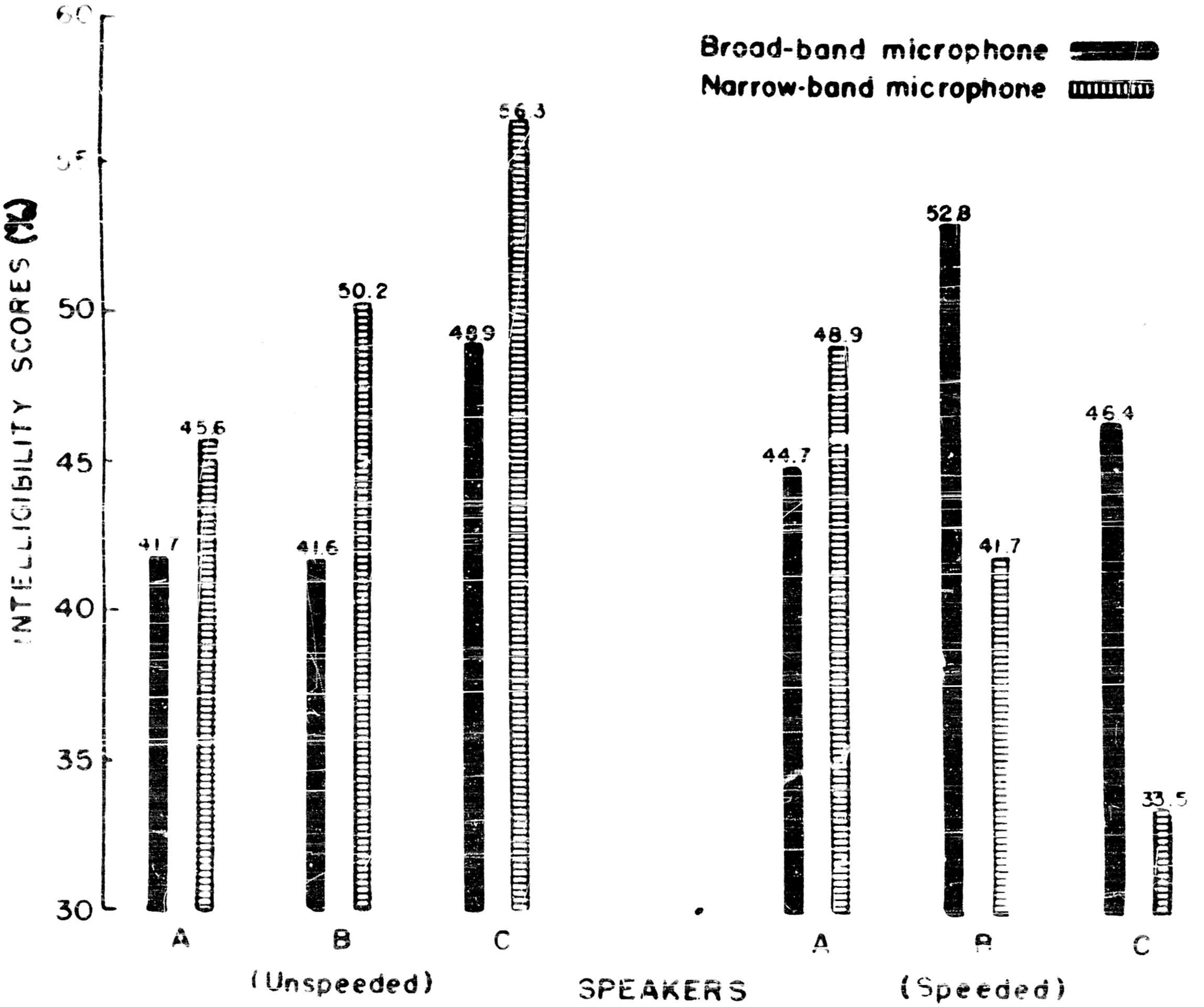

FIGURE I. INTELLIGIBILITY SCORES OF THREE PORTIONS (SPEAKERS) OF THE RESPONSE READINESS TEST AS TRANSMITTED THROUGH A BROAD-BAND AND A NARROW-BAND MICROPHONE.

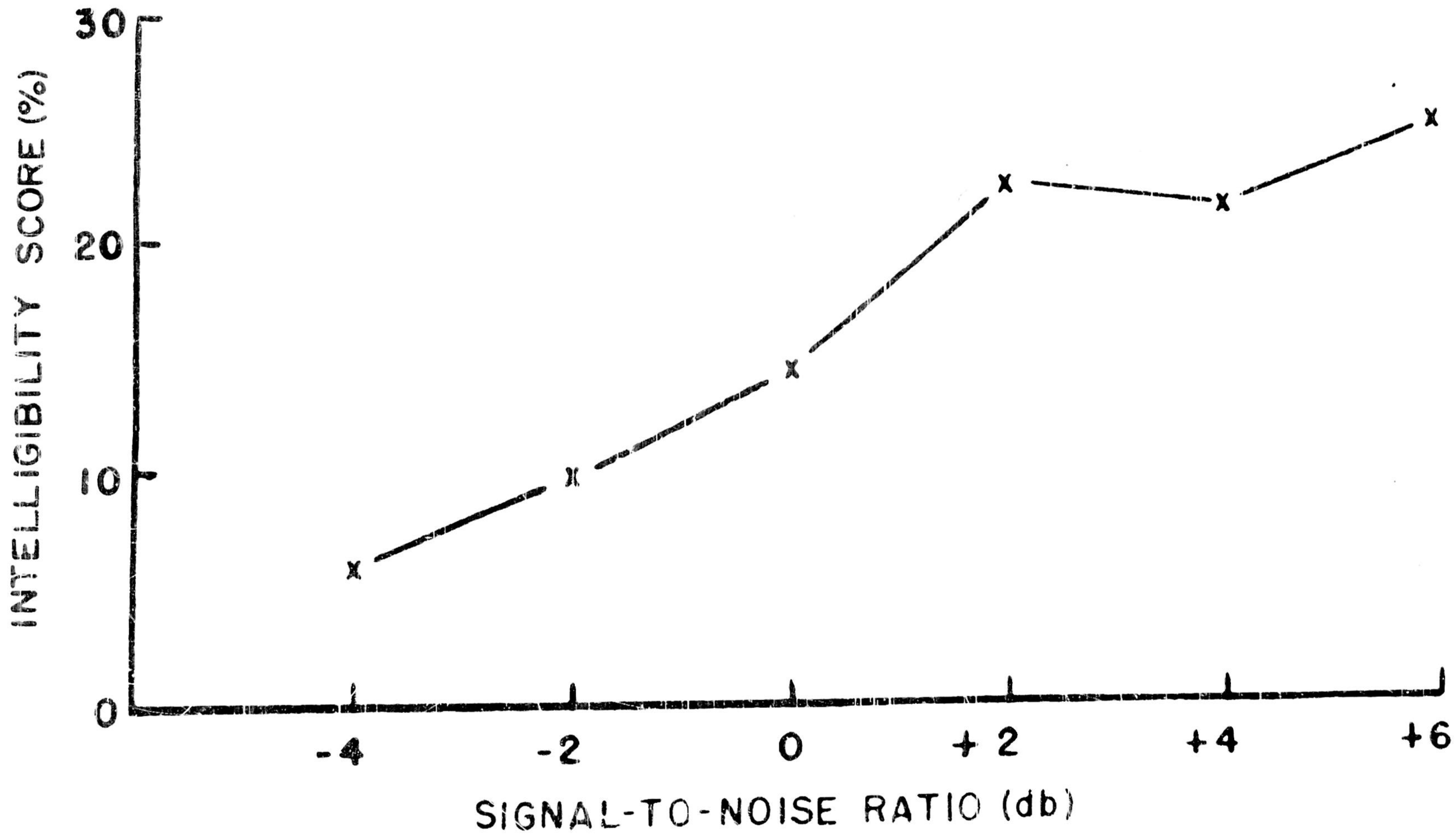

FIGURE 2. INTELLIGIBILITY SCORES OF A BROAD-BAND AND A NARROW-BAND MICROPHONE (POOLED) OPERATING IN SIX SIGNAL TO NOISE RATIOS.

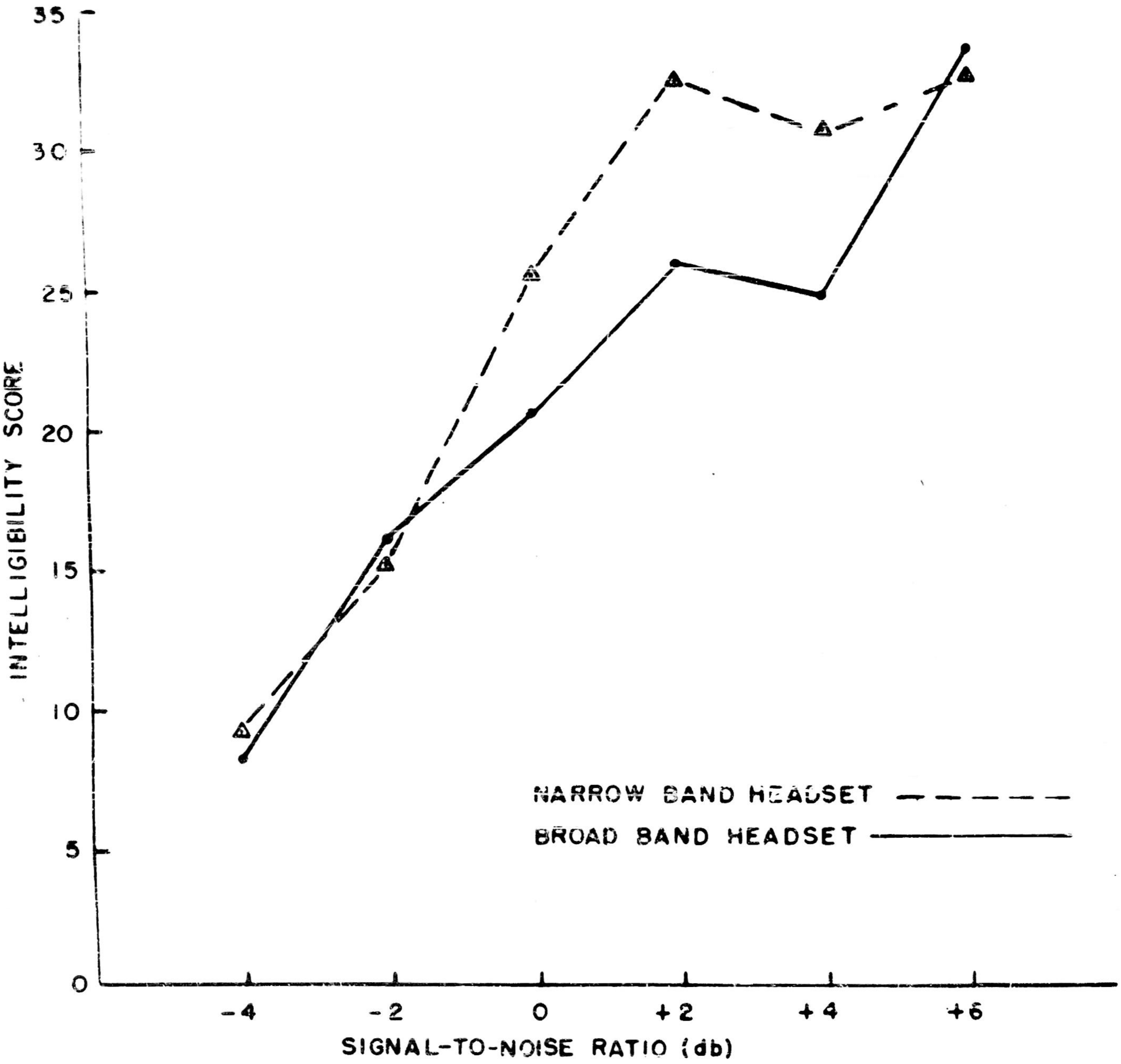

FIGURE 3. INTELLIGIBILITY SCORES OF A BROAD-BAND AND A NARROW-BAND HEADSET OPERATING IN SIX SIGNAL-TO-NOISE RATIOS.

Figure 4. Listener response Form 1, adopted from Form C of the Multiple-Choice Intelligibility Tests and from the pulse test.

TEST NO. 1

	TONE	SPEECH			NOISE
1		groove drew crew grew	modern moderate modesty modest	vice fight mice bite	
2		say stay stayed spade	forbade pervade surveyed survey	chink kink check chin	
3		stung stun sun stunned	drunk grunt brunt runt	intent intend content intense	
4		quench went whence when	busy physics physic visit	wade waves wave way	
5		pass past cast task	clearly weary quarry query	fine find sign kind	
6		popular poplar hopper opera	nurse first birth burst	get gap guess guest	
7		immense commence emit cement	named name main knave	only woman pullman omen	
8		latter ladder lattice rabbit	last lash laugh class	swain slain flame plain	
9		crash crab craft crack	gold bowl cold bold	pail poor polo palace	

TEST NO. 2

	TONE	SPEECH			NOISE
1		ninety nineteen nightly nine	drum rung rum run	harrow peril herald arrow	
2		ran rank rang rag	putter tucker pocket pucker	need lead lean leave	
3		kick tick pick hick	see seed siege seize	depot people equal decoy	
4		shower scholar sour scour	earthen earthly urban bourbon	bath bat bad back	
5		berry carry bearing very	spring pray spray spread	listless mistress restless blissful	
6		mouse mouth now mount	Saturn set second satin	fog bar beg bug	
7		quarter fortress portrait porter	felt belt dealt bell	horrible orchid orphan organ	
8		heavy happen package happy	did live led lid	dollar jealous zealous develop	
9		hamper pamper panther pamphlet	tendon tender pendant pendulum	pond on hound pawn	

TEST NO. 3

	TONE	SPEECH			NOISE
1		apply supply amply fly	gift if hit it	lamp lance glance land	
2		bust fuss but bus	handle anvil amble ample	free freeze freed tree	
3		airy hairy arid carry	fed stead spend sped	laugh glad lash flash	
4		throw froze prose probe	low rose loathsome lonesome	rod brown brow proud	
5		desk depth dead death	stance stand stamp spent	science silent sound silence	
6		broke growth throat wrote	code told cold coal	begun begot forgot deduct	
7		sister system cistern pistol	hulk halt pulp fault	mild mile miles mine	
8		strike spite fight spike	limp limb lend lent	town townsman townsmen count	
9		paid page age haze	cute cunning honey puny	fell spell felled bell	

TEST NO. 4

	TONE	SPEECH			NOISE
1		much mud month monk	uplift uproot approve group	cypress cipher siphon sightless	
2		twelve well dwell weld	mind mild mine line	blister blissful listful wistful	
3		wren went rent lent	barter barker sparkle parker	found crown cloud clown	
4		guide die died dive	lively widen wisely widely	love lull low lag	
5		stove sold stole soul	amiss omit amid emit	equipped acquit equip quit	
6		reverse traverse perverse pervert	sired siren fire sire	simple dimple pimple temple	
7		drove stroke strode strove	warrant one warm warn	dog gone don darn	
8		fire hire tired tire	stale jail dale gale	evil easel measles needle	
9		gaily fail daily five	barn bark bought spark	lip lift lisp list	

TEST NO. 5

	TONE	SPEECH			NOISE
1		crash drag trash thrash	least lease piece leaf	wouldn't wood wooden wooded	
2		pillow pillar killer filler	peg keg egg pay	loosely gruesome loosen nuisance	
3		lava loud lock robber	wait which wake wig	hour how howl owl	
4		glad lad laugh lag	fable tablet habit cattle	part art heart arch	
5		puncture teacher tincture picture	sigh size side scythe	bake bait fate faith	
6		tempt tense tent hemp	green cream tree creed	seller solemn solid sullen	
7		youth you use mute	allege away allayed allay	muster lusty bluster luster	
8		tight pike height hike	birds bird birth burden	chat cap check chap	
9		devise defy divide beside	chaff shaft chap shack	Ed head add ebb	

TEST NO. 6

	TONE	SPEECH			NOISE
1		feel deal steal veal	fruit true troop truth	pelvis elder elbow eldest	
2		tasty hasty hasten pastry	sheep shield she sheath	add ask as has	
3		wrist risk rip list	depth death deaf guest	fortune fort important forty	
4		shoe choose too chew	defense methinks repent bethinks	hamper tamper hampered hamburg	
5		led red ledge leg	palace palate talent pilot	stow stole stowed stove	
6		butter flutter flood fluttered	heat hate paint ink	tick chicken ticket picket	
7		thumb from come sum	coy toy tore torque	auto bottom often autumn	
8		bower borrow flower power	fast fact fat that	sit six sick sift	
9		deceive precede concede receive	cars carve card car	heard verge urge herb	

HEARING TEST RECORD CNATRA.907A PAT

Form 1

NAVY.PPO CNATRA.PENSACOLA.FLA

Figure 5. Listener response Form 2, adopted from Form C of the Multiple-Choice Intelligibility Tests and from the pulse test.

TEST NO. 7

	TONE	SPEECH			NOISE
1		providence problem promise province	worse work worst worth	pledge sled sledge sleigh	
2		rew throw grove grow	wearing wearer wary wear	stomach staunch stark starch	
3		suffer zipper supper zephyr	scram swing slam swam	grandsire grandstand transpire grandchild	
4		bathe [illegible] space spade	reverse invert divert revert	anew [illegible] amuse unuse	
5		depth deck death debt	dangling sandy sandwich sanguine	bristle brittle ripple riddle	
6		attend akin attempt again	bold fold bowl hole	steward sewer steal Stewart	
7		break rate rape rake	spurt stirrup sterile syrup	increase entreat retreat intrigue	
8		tack tax facts tact	souse south sound sack	mystery mystic mischief misty	
9		anew balloon aloof allude	oake date bait fake	rhythm written ridden ribbon	

TEST NO. 8

	TONE	SPEECH			NOISE
1		eighty acre aching eight	trump front truck trunk	irk hurt earth heard	
2		delude remove elude renew	head edge hedge egg	gauge gaze gave gay	
3		can't scant scamp scan	arm armed on odd	flatter climate planet plant	
4		find bind vine fine	purse burst hurt first	fitness thickness sickness picnic	
5		dumb gum dump done	bedroom reverend brother brethern	royal broil broiled boil	
6		snout smelt snub snap	wide why wise ride	afford abhor accord ashore	
7		stead dead sped bed	price Christ fight strike	bury barely fairly fairy	
8		white poison hoist voice	gown down gam gauze	error errand barren Arab	
9		next nets mix neck	racket blacken blackened black	drab draft graft grab	

TEST NO. 9

	TONE	SPEECH			NOISE
1		bite bike vice fight	apple applause applaud apply	pulse fault pulp false	
2		space attain face aface	runny rubbish ready ruddy	goose noose use deuce	
3		bruise brood brew cruise	by spy fire five	rather letter lever leather	
4		bramble scramble gravel ramble	love mart larm lark	hence tense tent hint	
5		stain stink sting sing	patron patient hasten paper	train crane brain frame	
6		groom prune broom room	cub tug tough tub	listen christen Christmas prison	
7		handsome cancer camphor cancel	parcel handle partly parsley	fear peer hear tear	
8		suit soon soothe sue	cotton coffin coffee copy	neither meter meager leader	
9		steam seen speed esteem	hump hunt pump punk	exalt result gulf exhaust	

TEST NO. 10

	TONE	SPEECH			NOISE
1		artist harness harvest orchid	vesper faster pester festive	knoll known no mold	
2		simple sinful summon stomach	bomb bound bond barn	Boston frosty frosting cross	
3		litter little glitter liquor	wrestle rascal rapture raffle	pope hope oak post	
4		main mink make mate	twelve welt wealth twelfth	march margin marching Martin	
5		lengthen ointment Lincoln link	geese east meat yeast	rain wing green ring	
6		bud bus bust but	rough drunk rump rum	hearing hairy carry herring	
7		pleasant pheasant peasant present	widen wide wife wagon	saint safe faint sink	
8		winter winner where woman	model marvel marvelous marble	log lawn blond long	
9		lose loose loot blue	itself excel sell himself	mash gnash smash nag	

HEARING TEST RECORD CNATRA-987B PAT

TEST NO. 11

	TONE	SPEECH			NOISE
1		toward forge ford board	feeling dealer fever feeler	dome don't none stone	
2		destroy deprive defraud defrost	girl pearl curled curl	flicker slipper liquor quicker	
3		chart short shark sharp	frightful rifle greatful rightful	sultry culprit sculpture sculptor	
4		native navy naked nature	pearl crow throw grow	calf cad calves cab	
5		lathe lay laid leg	candy pantry pansy handy	ink pinch inch hint	
6		thus bust duck dust	legend ledger leaden lesson	hit fist this kiss	
7		bulb bulge bald ball	cut carpet cotton copper	net met neck neat	
8		breast friend breath bread	Capital hapless hatless happen	glass lad blast black	
9		harbor harder ardor artist	soft sought salt sulk	hood could put good	

Form 2

TEST NO. 12

	TONE	SPEECH			NOISE
1		needle evil meal neither	large lodge lie live	haven heaven even able	
2		dimple gentle devil dental	interval penguin hindrance kindred	cast past pass path	
3		armload armholed armhole armful	pen ten tend tent	wooden woody wood witty	
4		gem gent gin gym	glaze play blade blaze	creeping greeting greedy reading	
5		flush pledge fresh flesh	size sigh scythe side	waitful wake wasteful wakeful	
6		auburn often author autumn	astride ascribe prescribe describe	dial guile vial guide	
7		nest mess meant met	rug love rough rue	harrow herald arrow peril	
8		grain raise raid rage	bench theft fetch thatch	nuptial nocturnal nutshell neptune	
9		flapper leopard leper letter	stole stone school scold	wallet swallow wall wallow	

NAVY-PPO CNATRA, PENSACOLA, FLA.